FUNDAMENTAL COMPARISON OF

THE ARROWBIO PROCESS

AND OTHER ANAEROBIC DIGESTION SYSTEMS

by

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Abstract: The premise of the ArrowBio Process differs fundamentally from that of other anaerobic digestion systems. The difference revolves around water. Other systems "fight" water whereas ArrowBio exploits it, at both front and back ends of the system. At the front end biodegradable and non-biodegradable materials are separated gravitationally, and the biodegradables prepared for digestion. At the back end rapid biological action is realized, as is possible only with UASB (watery) digestion. These matters have been detailed in previous submissions to the City as they pertain to ArrowBio. The present analysis compares ArrowBio to other anaerobic digestion systems.

Appended to this document is an accessible explanation of UASB digestion.

Feed Thickness as Key Determinant

Anaerobic digestion of MSW involves technologically complex systems. Commercial technologies differ from one another in many details, but a single factor drives overall design: this is the thickness of the organic feed to the facility's biological component.

There are two clusters of systems: the ArrowBio Process and the others (Table 1).

Table 1. Feed thickness as the key determinant of anaerobic digestion facility design and performance

Digester feed thickness (% solids)	Pre-digestion (separation/ preparation)	Management of the microbial community (anaerobic digestion per se)	Post-digestion (amount and condition of digestate)	System (commercial offerings)
High solids (15-40% thick slurry or paste)	Exclusively in air	Conventional: high rates of microbial action not attainable.	Large amount, poorly stabilized, considerable M-mFM present[3]	Other processes
Watery (3-4% solids)	In water[1]	UASB[2]: high rates of microbial action attained	Small amount, well stabilized, little M-mFM[3]	ArrowBio Process

[1] There may be a minor "pre-water vat" step (see 22 July 2005 response to NYC).
[2] UASB = Upflow Anaerobic Sludge Blanket digestion (see earlier detailed descriptions).
[3] Man-made Foreign Matter (glass, ceramic, metal, film plastic, rigid plastic, synthetic fabric).

The tables and narrative that follow illustrate the inescapable logic of facility design flowing from the thickness of the facility feed.

Pre-digestion Function

Purpose: Operations prior to digestion involve the separation of the non-biodegradable and biodegradable fractions of a mixed waste. Several overlapping purposes are served: recovering traditional recyclables, protecting downstream equipment, isolating the biodegradable organics, preparing the organics for subsequent digestion, excluding Man-made Foreign Matter (M-mFM) from the digestate.

Other processes: The Refuse is processed in air (low buoyancy) to separate materials and prepare the organics for digestion. Water-based separation/preparation is not possible because it is incompatible with the unit process to follow – that of conventional anaerobic digestion. The feed remains in solid or semi-solid form. Adjustment of the moisture content may be necessary.

ArrowBio Process: The Refuse is tipped into water (high buoyancy) in a separation/preparation vat (but see Table 1 footnote 1). This watery step is not only possible but it is necessary, as dictated by the nature of the UASB variant of anaerobic digestion to follow. The basic separation driving force is gravity expressed through water. The biodegradable organics come into solution and fine suspension.

Remark: Because of their differential buoyancies, water is vastly superior to air as a separation medium. Moreover UASB digestion, with its many advantages, requires that the solid phase organics be rendered into watery form (Table 2).

Table 2. Separation/preparation in High Solids technologies and the Watery ArrowBio Process

Factor or function	**High solids technologies**	**Watery ArrowBio Process**
Separation medium	Air	Water[1]
Accepts mixed MSW	Varies	Yes
Absorbs dust	No	Yes
Absorbs odor	No	Yes
Isolation of biodegradable organics	Incomplete	Nearly complete
Integrated with anaerobic digestion (subsequent function)	No[2]	Yes[3]
Burden of M-mFM in prepared feed	Large	Small

[1] The water comes from the waste.
[2] Front-end separation/preparation is a stand alone unit process
[3] Front and back-end functions (separation/preparation and digestion) are integrated in that the front-end supplies the prepared feed to the back-end, which reciprocally supplies feed-derived makeup water and electrical energy to the front-end.

This table illustrates how the "solids content" point of departure determines the pre-digestion unit process pf separation/preparation.

Anaerobic Digestion Function

Purpose: The central purpose of an anaerobic digestion system is to transform biodegradable organic material to biogas and digestate (compost). The more gas produced and the higher its methane content, the better. The less digestate produced and the more highly stabilized its condition, the better. The two are reciprocals of one another in that the more complete the transformation of organics to methane, the less the amount of compost produced and the more stabilized its condition. Also, the gasification of organics leaves behind its moisture content in liquid form. With respect to the subsequent unit operation, the more complete the biological action, the less need for post-digestion composting (curing).

High Solids technologies: The moisture content of the solid organic material is adjusted as needed to make a thick slurry or thicker paste according to the particular system design, with mechanical mixing as required. The prepared material is transferred mechanically to a one-stage (conventional methanogenic only) or two-stage (acidogenic followed by conventional methanogenic) system.

ArrowBio Process: The watery stream of well isolated organics in solution and fine suspension is pumped to the two-stage digester system (acidogenic stage followed by UASB methanogenic stage).

Remark: Anaerobic digestion per se is, of course, the heart of the system. The key point is how the microbial community is (or can be) organized, hence how thorough the transformation of organics to methane and digestate. The thoroughness determines what approach may be taken to the prior separation/preparation function, and also to the subsequent curing function (Table 3).

Table 3. Anaerobic digestion in High Solids technologies and the Watery ArrowBio Process

Factor or function	High solids technologies	Watery ArrowBio Process
Feed	"High Solids" (thick slurry), or "Very High Solids" (thicker paste)	Watery
Organization of microbial community	As in conventional digestion	As in advanced UASB digestion[1]
Efficiency in use of bioreactor volume	Very low	Very high
SRT/HRT (days)	15/15	80/1
Rate of biological action	Slow	Fast
Extent of biological action	Slight	Considerable
Biogas methane/CO2 ratio (%)	55/45	75/25
Amount of biogas	Small	Large
Amount of digestate	Large	Small
Condition of digestate	Poorly stabilized, contaminated	Well stabilized, clean
Amount of anaerobic biological work done per facility footprint area[2]	Very small	Very large

[1] In UASB digestion the microbes organize themselves into "granules," each of which is a functionally complete microcosm. This form of organization is possible only with a feed that is watery. UASB is the favored technology for strong wastewater; its use for MSW is unique to the ArrowBio Process.

The practical import of Table 3 can be summarized as follows: the UASB microbial community does vastly more work per unit reactor volume. Hence the larger amount of biogas richer in methane, and the smaller amount of more thoroughly stabilized digestate.

Post-digestion Function

Purpose: The purpose is to condition the digestate for ultimate use.

High Solids technologies: The digest may, or may not, be dewatered, depending on the solids content of the digestate and the needs of the composting system.

ArrowBio Process: The digestate is dewatered employing, for example, a belt-filter press. A portion of the water is recycled to the separation/preparation unit as makeup water. The need for composting, if any, is slight.

Remark: Relating Table 4 below to the preceding Tables 2 and 3 shows how "one thing leads to another," and how, as summarized in Table 1, all starts with feed thickness.

Table 4. Digestate in High Solids technologies and the watery ArrowBio Process

Factor or function	**High Solids Technologies**	**Watery ArrowBio Process**
Amount of digestate	Large	Small
Condition of digestate	Poorly stabilized	Well stabilized
Need for composting	Major unit process[1]	Minor passive system – if any
Presence of M-mFM in final product	Substantial	Slight

[1] The composting component may be as large and involved as the rest of the plant put together. The potential for nuisance odor is substantial.

The relative freedom of ArrowBio compost from Man-made Foreign substances is attributable to water-based separation. As documented in studies cited in our 22 June 2005 response to the City (p.16), air-based separated results in troublesome amounts of M-mFM.

Final Comment

New York City needs to demonstrate a direction to be honed and expanded over perhaps a decade to maximize the recovery of material and energy resources from the Refuse fraction, while minimizing landfilling and environmental impacts. The success of this endeavor is dependent on the fundamentals of the selected technology. As demonstrated in this comparative analysis, the ArrowBio Process is prepared to serve that need.

Appendix -- Why Watery Digestion?

A Metaphor Supplementing

ArrowBio's Presentation to NYC and ARI

28 July 2005 in Concord, Massachusetts

The ArrowBio Process for MSW utilizes a watery anaerobic digestion system, whereas other commercial processes are far less watery – let's say 96% water vs. a soggy 70% water (= "high-solids"). Since we are not treating water, but rather biodegradable organics, isn't a watery feed wasteful of bioreactor volume? Perhaps surprisingly, it is not! In fact, the opposite is true.

The question about the proportion of water may be usefully rephrased: Is more microbiological work done per unit reactor volume per time in a watery or a high-solids system? Given UASB digestion, the watery system comes out way ahead.

The work of anaerobic digestion is done by a community of microbes made up of different specialist populations, each population doing only one biochemical operation. The mixed metaphor of a bucket brigade putting out a fire may be a useful way of viewing events.

Microbial population **A** pours its water (= its part of the work) into **B**'s bucket, **B** into **C**'s, **C** into **D**'s…. and so forth…. until the work is completed (fire out, or fresh organics transformed into the end products methane, carbon dioxide, free liquid water, and depleted organic residue.)

In the high-solids digester the bucket brigade is in a state of disorganization. It's as if **A** first has to search for **B**, who is out there in the woods somewhere. Only on finding **B** can **A** can pour his/her work product into **B**'s bucket. Now **B**'s problem is to find **C**, and so forth. This type of brigade, to continue our metaphor, is no way to fight a forest fire!

With UASB digestion, the bucket brigade is effectively organized into a straight, tight, line from water supply truck to the fire's edge. The fire is soon out. Or, back to MSW, the fresh organics in the feed have been efficiently transformed to the desired end products.

In technical terms this is the result of SRT>>>HRT, which is possible only with watery feed -- that is, with UASB digestion. In the ArrowBio Process for MSW, it all starts in the up-front water vat.

I hope this is found to be useful.

Mel Finstein